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Modeling Energy Consumption of Residential Furnaces and Boilers in U.S. Homes

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ABSTRACT

In 2001, DOE initiated a rulemaking process to consider whether to amend the existing energy efficiency standards for furnaces and boilers. A key factor in DOE's consideration of new standards is their cost-effectiveness to consumers. Determining cost-effectiveness requires an appropriate comparison of the additional first cost of energy efficiency design options with the savings in operating costs. This report describes calculation of equipment energy consumption (fuel and electricity) based on estimated conditions in a sample of homes that are representative of expected furnace and boiler installations. To represent actual houses with furnaces and boilers in the United States, we used a set of houses from the Residential Energy Consumption Survey of 1997 conducted by the Energy Information Administration. Our calculation methodology estimates the energy consumption of alternative (more-efficient) furnaces, if they were to be used in each house in place of the existing equipment. We developed the method of calculation described in this report for non-weatherized gas furnaces. We generalized the energy consumption calculation for this product class to the other furnace product classes. Fuel consumption calculations for boilers are similar to those for the other furnace product classes. The electricity calculations for boilers are simpler than for furnaces, because boilers do not provide thermal distribution for space cooling as furnaces often do.

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1 INTRODUCTION

The National Appliance Energy Conservation Act of 1987 (NAECA) requires the U.S. Department of Energy (DOE) to consider amendments to the energy conservation standards to increase efficiency in residential furnaces and boilers. This equipment represents a large opportunity for savings because it accounts for 25-30 percent of the total primary energy used in U.S. residential buildings (which was around 21 quads in 2001).

Regulations that took effect in 1992 set the initial Federal energy conservation standard in terms of the Annual Fuel Utilization Efficiency (AFUE) descriptor at a minimum value of 78% for most furnaces, at 75% for manufactured-home furnaces, and at 75% for gas steam boilers and 80% for other boilers. In 2001, DOE initiated a rulemaking process to consider whether to amend the existing energy efficiency standards for furnaces and boilers. The rulemaking process used by DOE consists of a number of interrelated analytical steps. The Energy Efficiency Standards group at Lawrence Berkeley National Laboratory (LBNL) coordinated and conducted the technical analysis for DOE.[1]

A key factor in DOE's consideration of new standards is their cost-effectiveness to consumers. Determining cost-effectiveness requires an appropriate comparison of the additional first cost of energy efficiency design options with the savings in operating costs. The changes in consumer first cost and operating costs are both measured relative to a base case design. The base case represents the typical type of equipment that consumers would be likely to use in the absence of new standards.

The consumer operating cost has two components: annual energy cost and annual maintenance cost. The annual energy cost is the product of annual energy (gas or oil, and electricity) consumption times the price of each energy type. For the life-cycle cost (LCC) analysis of DOE's rulemaking process, energy consumption was calculated based on estimated conditions in a sample of homes that are representative of expected furnace and boiler installations. This report explains the calculation of energy consumption of furnaces and boilers conducted for the LCC analysis.[2]

The analysis considered six product classes for furnaces and boilers. The level of unit shipments for each class in 2000, based on data provided by the Gas Appliance Manufacturers Association (GAMA),[3] is shown in Table 1.1. Since non-weatherized gas furnaces comprise by far the largest class, DOE devoted the most attention to this product.

Table 1.1 Market Statistics for Furnaces and Boilers by Product Class

Product Class	**Estimated Shipments in 2000**	**Number of Models (2001)**
Non-weatherized gas furnaces	2,645,000	6907
Weatherized gas furnaces	325,000	4476
Non-weatherized oil-fired furnaces	120,000	868
Manufactured-home gas furnaces	130,000	70
Hot water gas boilers	190,000	990
Hot water oil-fired boilers	100,000	640

Sources: GAMA shipments data, GAMA Directory[4]

To represent actual houses with furnaces and boilers in the United States, we used a set of houses from the Residential Energy Consumption Survey of 1997 (RECS97) conducted by the Energy Information Administration (EIA).[5] For each house, RECS97 reports gas and oil space heating energy consumption and space-cooling electricity consumption. Our calculation methodology estimates the energy consumption of alternative (more-efficient) furnaces, if they were to be used in each house in place of the existing equipment. We developed the method of calculation described in this report for non-weatherized gas furnaces. We generalized the energy consumption calculation for this product class to the other furnace product classes. Fuel consumption calculations for boilers are similar to those for the other furnace product classes. The electricity calculations for boilers are simpler than for furnaces, because boilers do not provide thermal distribution for space cooling as furnaces often do.

2 FURNACE AND BOILER TECHNOLOGY OVERVIEW

Fuel-burning furnaces provide heat by transferring combustion products through a heat exchanger. Furnaces pass air over the outside of the heat exchanger, transferring the heat from the fuel to the air. Fuel-burning furnaces exhaust the products of combustion to the atmosphere through the flue passage connected to the heat exchanger. Furnaces use a fan to propel the air over the heat exchanger to circulate the air through the distribution system.

Manufacturers rate non-weatherized furnaces as if they are isolated from the conditioned space where they are located. In this isolated combustion system (ICS) rating, furnaces draw combustion and dilution air from the outdoors. This differs from the "indoors" rating, which assumes that the furnace draws the combustion and dilution air from the conditioned space.

Weatherized furnaces are only used as part of a package unit, which means that the air conditioner is in the same box. They are installed outside (often as a rooftop unit) and are properly insulated. We do not know of any manufacturer that presently sells a stand-alone furnace approved for outdoor installation. The main difference between a weatherized furnace and a non-weatherized furnace is that the weatherized furnace has insulation and an external case. Differences in jacket losses also affect test procedure results. The heat loss through the jacket in a weatherized furnace is totally dissipated outside, resulting in a lower efficiency compared to an equivalent non-weatherized furnace installed indoors.

Non-weatherized gas furnaces can be either non-condensing or condensing. Condensing gas furnaces recover so much heat from the combustion products that some of the water vapor condenses and turns into liquid. There are no condensing weatherized furnaces, because the condensate could freeze and damage the furnace. When the flue temperature is substantially higher than the water dew point and the latent heat (the heat from condensation) is lost in the flue, the furnace is classified as non-condensing.

If the furnace condenses the water (typically with the addition of a secondary corrosion-resistant heat exchanger) and drains it out, the flue temperature is much lower, and the efficiency is higher (over 90% AFUE).[a] A condensing furnace requires some additional equipment, such as an additional stainless steel heat exchanger and a condensate drain device. Condensing furnaces also require a different venting system, since the buoyancy of the flue gases is not sufficient to draw the gases up a regular chimney. Plastic through-the-wall venting systems are typically used in conjunction with condensing furnaces. Condensing furnaces present a higher initial cost, but provide significant energy savings.

Manufactured home furnaces are a separate class of furnaces, due to three differences. They employ sealed combustion, pre-heat the combustion air, and have very specific geometric configuration. These furnaces have historically had a lower efficiency standard and were considered as a separate product in DOE rulemakings in the early 1990s.

Boilers are heating devices that transfer heat from the combustion gases to water, which then heats up the required space through a hydronic (hot-water) or steam system. The technology used for steam boilers is the same as for hot-water boilers, except that circulating pumps are not used in steam boilers. Boiler capacities range greatly, but they tend to be higher than for furnaces.

Boilers on the market are distinguished by the type of material: cast-iron sectional, steel fire-tube, copper water-tube, and aluminum. Cast-iron boilers are the most popular and are typically gas-fired. Steel boilers are also fairly popular, are perceived to be less expensive, and are always oil-fired. Copper boilers are less popular and are typically used for particular short-response-time small systems. Aluminum boilers are relatively uncommon.

Hot-water boilers are found in all of the above material types. Steam boilers are either cast-iron sectional or steel fire-tube type.

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[a] AFUE = Annual Fuel Utilization Efficiency

Table 2.1 shows the current minimum efficiency levels for each product class, as well as the most common efficiency on the market.

Table 2.1 Furnace and Boiler Efficiency

Product Class	**Minimum AFUE**	**Most Common AFUE in 2001***
Non-weatherized gas furnaces	78%	80%
Weatherized gas furnaces	78%	80%
Oil-fired furnaces	78%	81%
Manufactured-home furnaces	75%	80%
Hot water gas boilers	80%	82-83%
Hot water oil-fired boilers	80%	86%

* Based on number of models in GAMA Directory

3 METHOD FOR NON-WEATHERIZED GAS FURNACES

To begin the analysis, we developed representative "virtual" furnaces.[a] These virtual models incorporated typical features of currently-marketed furnaces. We based the virtual furnaces on models selected from directories and product literature. The virtual models capture the range of actual furnace sizes. We assigned an appropriate virtual furnace to each sample house as a way of modeling energy consumption of alternative furnace designs.

Estimating the energy consumption of alternative furnaces used in each house required derivation of the heating and cooling loads of each house. These loads represent the amount of heating and cooling required by a house to keep it comfortable during an entire year. We estimated the heating and cooling loads from the heating and cooling energy consumption and the assumed characteristics of the existing furnace and air conditioner in each sample house. We assigned the characteristics of the existing furnace and air conditioner to each sample house, depending on the size and climate zone of each house and the age of the heating equipment. The estimation of heating and cooling loads also required us to calculate the electricity consumption of the furnace blower, since heat from the furnace blower and blower motor contributes to heating the house.

To complete the analysis, we calculated how much energy would be required by furnaces with alternative efficiency levels and design options to meet the same heating and cooling load of each sample house.

[a] We use the term "virtual" to indicate that these are conceptual furnaces rather than actual furnaces on the market.

4 VIRTUAL FURNACE MODELS

We intended the virtual furnace models to represent typical furnaces with basic features, but not to describe specific existing furnaces. We derived the characteristics of the virtual furnace models from existing "basic" furnace models, after examining directories and product literature of existing furnaces. See Appendix A, Database of Reduced Set of Furnace Models, for more details.

As a starting point for choosing values of input capacity for the virtual furnace models, we looked at the number of models listed by input capacity in the GAMA Directory of April 2002 [4] (see Figure 4.1). We selected models that were non-weatherized gas furnaces not designed for manufactured homes, and that were not discontinued. Using these selection criteria, we reduced the 36,032 gas furnace models in the GAMA Directory to 15,881 models. For virtual furnaces, we selected twelve input capacities that were the most common and that spanned the range on the market. We made these selections based on the assumption that the sizes with the most models are the most popular (see Table 4.1).

We defined airflow capacity as the nominal maximum airflow at 0.5 inches water gauge (in.w.g.) external static pressure, as listed in the product literature for each model.[a] Manufacturers usually code this airflow capacity in the model number. (See Appendix B, Manufacturer Model Numbers, for more details.) Most of the furnaces fit into four airflow capacity sizes: 800 cubic feet per minute (cfm), 1200 cfm, 1600 cfm, and 2000 cfm. These airflow capacities correspond to nominal air-conditioner sizes of two tons, three tons, four tons, and five tons, respectively. We used the same set of airflow and capacity sizes for both non-condensing and condensing furnaces.

[a] Furnaces are capable of providing several levels of airflow. For heating operation, a low level of airflow is used. If the furnace provides airflow for an air conditioner during cooling operation, it is typically set to provide a higher level of airflow when the air conditioner is operating.

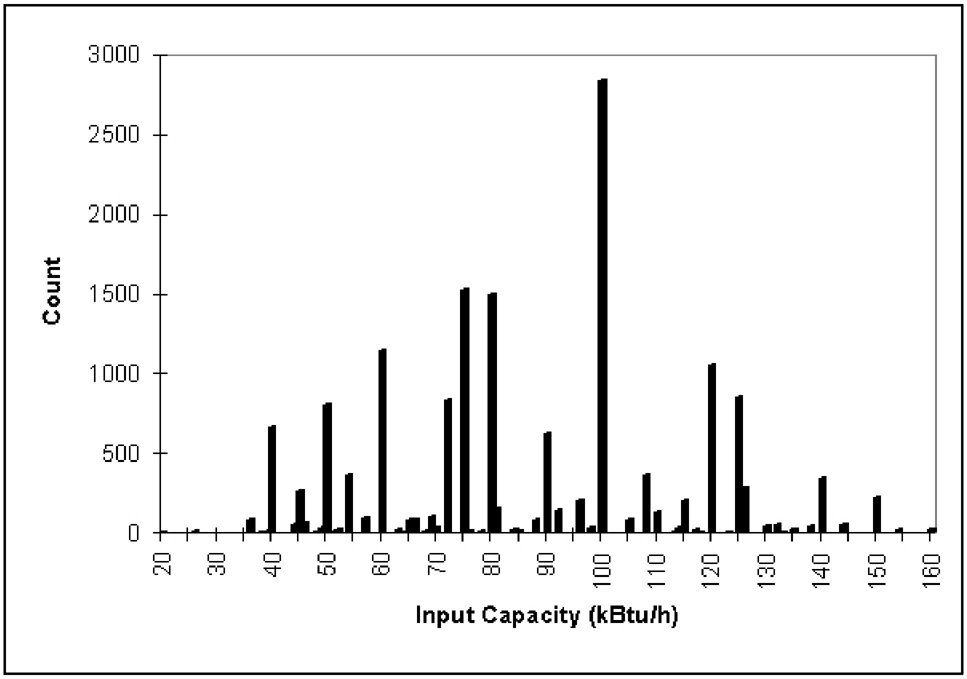


Figure 4.1 Number of Furnace Models by Input Capacity

4.1 Basic Actual Furnace Models

We selected actual furnace models that represent the fundamental characteristics of non-condensing and condensing furnaces with no special features. We used the characteristics listed in Table 4.1 to select basic furnace models. These characteristics are the most common among models on the market. We selected several dozen furnace models that have these features and looked in detail at these basic models to determine specific characteristics to use for creating virtual furnaces.

Table 4.1 Characteristics of Basic Furnace Models

Non-Condensing Gas Furnace	Condensing Gas Furnace
single-stage burner	single-stage burner
80% AFUE	90-92% AFUE
PSC blower motor	PSC blower motor
forward-curved fan impeller blades	forward-curved fan impeller blades
up-flow or horizontal air-flow	down-flow, up-flow, or horizontal air-flow

The basic furnace models are listed by brand and series in Appendix C, Basic Furnace Model Determination.

4.2 Input Capacity and Maximum Airflow

For virtual furnace models, we selected 25 combinations ("bins") of input capacity and maximum airflow. The marked cells in Table 4.2 reflect the input capacity and maximum airflow values for the virtual furnace models. The selection reflects the most common input and nominal maximum airflow capacities of models in the GAMA Directory April 2002 database, in product literature, and listed on furnace manufacturer web sites. Most basic models on the market fit into the 25 bins of input capacity and airflow capacity. Some models do not exactly match the bins, but their values are close enough that we included them in one of the 25 bins. For example, 40 kBTU/h and 45 kBTU/h models are grouped together into a single 45 kBTU/h bin. Most bins have at least two actual models.

Table 4.2 Virtual Furnaces: Capacity and Airflow

		Input Capacity (kBTU/h)											
		45	50	60	70	75	80	90	100	115	120	125	140
Maximum Airflow (at 0.5" Static Pressure)	800 cfm (2 tons)	x	x	x									
	1200 cfm (3 tons)	x	x	x	x	x	x	x	x				
	1600 cfm (4 tons)				x	x	x	x	x	x	x	x	
	2000 cfm (5 tons)							x	x	x	x	x	x

Because of the limited number of sizes available for manufactured-home gas furnaces and oil-fired furnaces, we selected a subset of the 25 input and airflow capacity combinations to represent each product class.

We created one virtual model to represent all the models assigned to each bin. We used specifications from the actual models in each bin to determine the specifications for the corresponding virtual model. The specifications include blower size, motor size, supply-air outlet area, power consumption of the draft inducer and the igniter, and several delay times. These specifications are described in the sections below.

4.3 Blower Size

We selected a blower size (listed as nominal diameter in inches by nominal width in inches) for each virtual furnace model (see Table 4.3). The blower size is typical for the basic furnace models in each bin. Blower size increases with airflow capacity, but not with input capacity. We used four blower sizes—the same ones for condensing and non-condensing virtual furnace models. For the blower sizes of basic furnace models, see Appendix C.

Table 4.3 Assigned Blower Size by Airflow Capacity

Airflow Capacity (cfm)	Blower Size (inches)
2-ton models (800 cfm)	9 X 8
3-ton models (1200 cfm)	10 X 8
4-ton models (1600 cfm)	10 X 10
5-ton models (2000 cfm)	11 X 10

4.4 Motor Size

The motors for the basic furnace models are 6-pole permanent split capacitor (PSC) motors. The motors in the basic furnaces come with three to five taps that are used to set the motor speed. We assumed that, at high speed, the motors operate with a speed of 1075 revolutions per minute (rpm) to provide the nominal maximum airflow at 0.5 in.w.g.

We assigned motor size to virtual furnace models, as shown in Table 4.4, to reflect typical-size motors of the basic furnace models. Motor sizes are the same for non-condensing and condensing furnaces. The larger the airflow, the larger the motor size. For the blower motor size and number of blower motor taps of basic model furnaces, see Appendix C.

Table 4.4 Assigned Motor Size by Airflow Capacity

Airflow Capacity (cfm)	Motor Size (HP)
2-ton models (800 cfm)	1/5
3-ton models (1200 cfm)	1/3
4-ton models (1600 cfm)	1/2
5-ton models (2000 cfm)	3/4

4.5 Supply-Air Outlet Area

The supply-air outlet area is the opening from the furnace to the supply duct. The supply-air outlet area for basic furnace models increases with airflow capacity and input capacity. To capture this trend, we constructed a linear fit of the supply-air outlet area to input capacity and airflow capacity for condensing and non-condensing furnaces. See Appendix C for supply-air outlet areas of basic furnace models. We used the following equations to determine the supply-air outlet area of the condensing and non-condensing virtual furnace models:

$$S_{nc} = 0.9498 + 0.5505 \times (Q/1000) + 0.0073 \times (Qin)$$

$$S_{c} = 0.7882 + 0.5006 \times (Q/1000) + 0.0087 \times (Qin)$$

where:

S	= supply-air outlet area (sq. ft.) for non-condensing (*nc*) and condensing (*c*);
Q	= nominal maximum airflow (cfm) at 0.5 in.w.g. static pressure; and
Qin	= input capacity (kBtu/h).

Figures 4.2 and 4.3 show the data points for supply-air outlet area for basic furnace models and the linear plane fit used to fit these points.

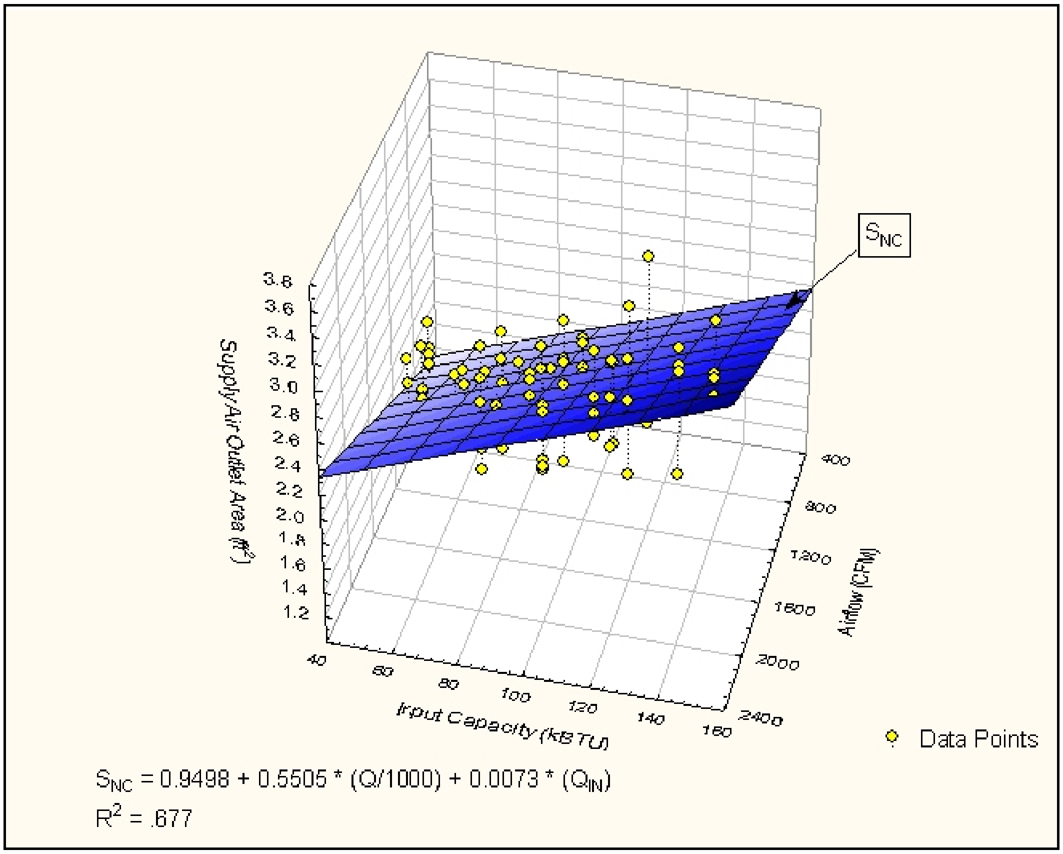
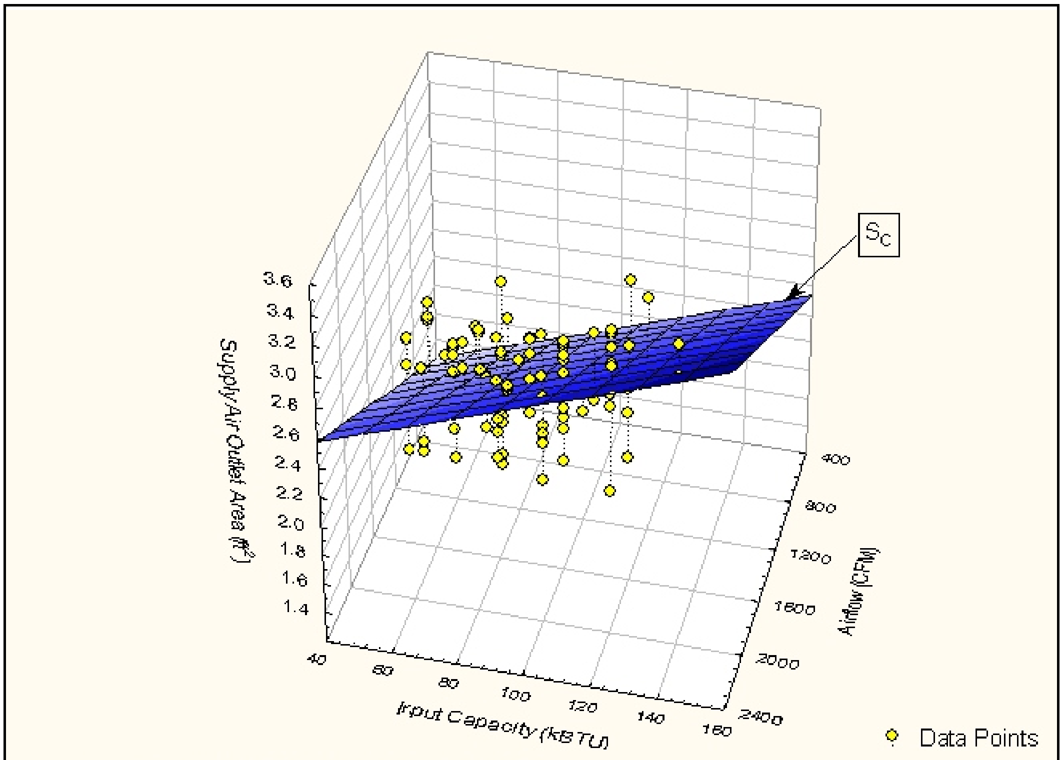


Figure 4.2 Supply-Air Outlet Area for Non-Condensing Natural Gas Furnaces



$S_C = 0.7882 + 0.5006 * (Q/1000) + 0.0087 * (Q_{IN})$

$R^2 = .654$

Figure 4.3 Supply-Air Outlet Area for Condensing Natural Gas Furnaces

Tables 4.5 and 4.6 show the values used for supply-air outlet areas for non-condensing and condensing virtual gas furnaces. The supply-air outlet area is larger for condensing models. The larger opening compensates for the increased pressure drop due to the secondary, condensing heat exchanger. This larger supply-air outlet area reduces the pressure drop across the furnace, so that the pressure rise for condensing furnaces is the same as non-condensing model furnaces at the same airflow.

Table 4.5 Supply-Air Outlet Area for Virtual Non-Condensing Gas Furnace Models

Input Capacity (kBTU/h)

Maximum Airflow (at 0.5" Static Pressure)	45	50	60	70	75	80	90	100	115	120	125	140
800 cfm (2 tons)	1.58	1.62	1.71									
1200 cfm (3 tons)	1.78	1.82	1.91	2.00	2.04	2.08	2.17	2.26				
1600 cfm (4 tons)				2.20	2.24	2.29	2.37	2.46	2.59	2.63	2.68	
2000 cfm (5 tons)							2.57	2.66	2.79	2.83	2.88	3.01

Table 4.6 Supply-Air Outlet Area for Virtual Condensing Gas Furnace Models

Input Capacity (kBTU/h)

Maximum Airflow (at 0.5" Static Pressure)	45	50	60	70	75	80	90	100	115	120	125	140
800 cfm (2 tons)	1.72	1.76	1.83									
1200 cfm (3 tons)	1.94	1.98	2.05	2.13	2.16	2.20	2.27	2.35				
1600 cfm (4 tons)				2.35	2.39	2.42	2.50	2.57	2.68	2.72	2.75	
2000 cfm (5 tons)							2.06	2.79	2.90	2.94	2.97	3.08

4.6 Power Consumption of Draft Inducer

A common value for power consumption of the draft inducer (PE) for basic non-condensing model furnaces is 75 W, and the average value is about 75 W, so we selected 75 W for all the virtual non-condensing models. We found no correlation between the power consumption of the draft inducer and either input capacity or airflow capacity. For condensing furnaces, we used a PE of 90 W, which closely matches the mean for that group. See Appendix C for the power consumption of the draft inducer in the basic models.

4.7 Delay Times

Pre- and post-purge times are the lengths of time the draft inducer operates before and after a firing cycle. On-delay is the amount of time the blower waits to begin operating after the burner starts firing. Off-delay is the time the blower keeps operating after the burner turns off. Ignition time is the length of time the hot surface ignitor is on before gas is sent to the burner.

Pre-purge, post-purge, on-delay, and off-delay times are not related to cfm or input capacity. We selected common values for the delay and ignition times of condensing and non-condensing virtual furnace models (Table 4.7). For this data for basic furnace models, see Appendix C.

Table 4.7 Values for Delay and Ignition Times

Pre-Purge	Post-Purge	On-Delay	Off-Delay	Ignition
15 seconds	5 seconds	30 seconds	120 seconds	37 seconds

5 ASSIGNING EXISTING EQUIPMENT TO SAMPLE HOUSES

To estimate the heating and cooling load of each sample house, we characterized the existing furnace in each sample house with respect to input capacity, airflow capacity, AFUE, and (for the air conditioner, if the house has one), seasonal energy efficiency ratio (SEER). As part of the heating- and cooling-load calculations, we estimated the electricity consumption and efficiency of the furnace blower motor. We used the input capacity and airflow capacity determined for the existing furnace to select the virtual furnace model to assign to each house.

5.1 Furnace Input Capacity

We assigned an input capacity for the existing furnace of each house based on an algorithm that correlates input capacity with the house size, the year the furnace was installed, and the distribution of input capacity of new furnaces sold the year the furnace was installed. The following steps describe the assignment process.

(1) We ranked all the RECS97 houses in ascending order by size (square foot) and calculated the percentile rank of each house using the weight of the sample records.
(2) We constructed percentile tables by input capacity of furnaces sold each year for 1997 and prior years, based on the historical shipment information for each year from GAMA.[3]
(3) After selecting a house from the RECS97 database during each Monte Carlo iteration, we noted the size of the selected house and determined the percentile rank from Step 1.
(4) To avoid a one-to-one deterministic relation between the house size and input capacity, we added a random term to the percentile identified in Step 3 so that the correlation was not perfect. We used a normal distribution to characterize the random term. The random

term has a mean of zero and a standard deviation of 8%.

(5) Using the percentile from Step 4, we looked up the input capacity from the input capacity percentile table in Step 2 for the age of the equipment.

Figure 5.1 shows the percent of existing furnaces by the input capacity assigned to the sample houses.

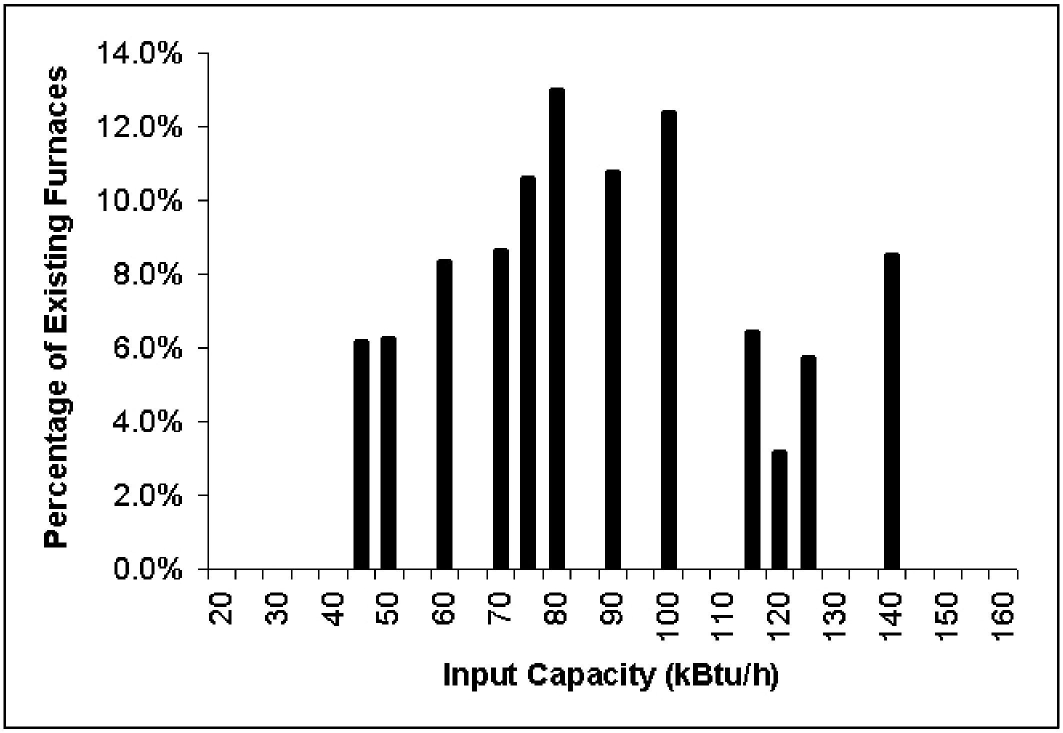


Figure 5.1 Percent of Existing Furnaces by Input Capacity

5.2 Airflow Capacity

We classified furnaces by nominal maximum airflow in cfm at 0.5 in.w.g. of external static pressure. We assigned the airflow capacity of existing furnaces for houses that had air conditioners in a similar manner as we assigned input capacity. Larger air conditioners go to larger houses, according to the distribution of sizes of air conditioners sold the year the air conditioner was installed in that house. We used the air conditioner nominal size of two, three, four, or five tons to set the airflow capacity with a ratio of 400 cfm of airflow per ton of cooling. The steps were:

(1) Based on the historical shipment information of residential central air conditioners by capacity, we constructed the airflow capacity percentiles tables for air conditioners sold in 1997 and prior years. We restricted the airflow sizes to two, three, four, or five tons—the equivalent of 800, 1200, 1600, or 2000 cfm at 0.5 in.w.g. static pressure. The variation of

the distribution of the four airflow sizes over the years is small. Most of the annual sales of residential central air conditioners from 1976 to 1994 are in these airflow sizes.

(2) Since there are no available shipment data on the airflow capacity of furnaces, we used the airflow capacity of residential central air conditioners as a proxy. Using the adjusted percentile of house size from Step (4) in the Input Capacity selection, we determined the airflow capacity by looking up the percentile in the corresponding distribution of nominal air conditioner size for the age of the cooling equipment. We selected a virtual model with the identified airflow capacity. If no virtual model with the identified airflow capacity was available, we selected the virtual model with the same input capacity and the closest airflow capacity as a substitute.

(3) If the RECS record indicated that the house did not have an air conditioner, we still used the procedure from step (2) to determine the airflow capacity. In this case, we used the age of the house (or 30 years if the house was older than 30 years) as a substitute for the age of the cooling equipment.

5.3 Efficiency Characteristics of Existing Equipment

Shipments data from GAMA indicate that houses in colder regions receive more-efficient furnaces.[3] Therefore, we correlated the AFUE of existing furnaces with the heating degree days (HDD) to base 65°F associated with each sample house. The following steps describe this process:

(1) We sorted the RECS houses in ascending order of HDDs, and calculated the percentile rank of each house by HDD using the weight of each sample house.

(2) Based on the historical furnace shipment information sorted by AFUE, we constructed percentile tables of furnaces by AFUE for 1997 and prior years.

(3) After we selected a house from the RECS database during each Monte Carlo iteration, we noted the HDD of the selected house. We looked up the percentile rank of that house from the HDD percentile table developed in Step (1).

(4) We added a random uncertainty term to the HDD percentile found in Step (3) to account for variability within the sample. We used a normal distribution to characterize the uncertainty term. The distribution of values of the uncertainty term has a mean of zero and a standard deviation of 8%.

(5) Using the adjusted HDD percentile from Step (4), we determined the AFUE by looking it up from the AFUE percentile table from Step (2) corresponding to the age of the existing equipment in the house.

Houses with central air conditioners use the circulating-air blower in the furnace to circulate the conditioned air during the cooling season. If a house had an air conditioner, we assigned it a SEER level. Unlike AFUE, SEER was not correlated with any other housing factors. We constructed SEER distributions for all years from historical shipment data, and we randomly selected a SEER from the distribution for the year of the age of equipment in each house.

5.4 Electricity Consumption of Existing Furnace Blower

All furnaces manufactured since about 1980 use forward-curved impellers driven directly by a PSC motor. Thus, most existing furnaces have a blower and blower motor similar to those in the virtual furnace models.[a] Therefore, in assigning the electricity consumption of the existing furnace blower for each house, we assumed that the electricity use of the existing furnace was equivalent to the electricity use of the virtual furnace model described in section 3.

We calculated electricity use by the existing furnace from the fan curves, overall efficiency, airpower, and time delays of the virtual furnace model of the same input capacity and airflow capacity. The calculation procedure used is described below.

6 CALCULATING FURNACE BLOWER ELECTRICITY CONSUMPTION

The electricity consumption (and overall efficiency) of a blower motor depends on the speed at which the motor operates, the external static pressure difference across the blower, and the airflow through the blower. To calculate blower-motor electricity consumption, we determined the operating conditions (the pressure and airflow) at which a particular furnace in a particular house will operate. These operating conditions can be graphically displayed as the intersection of a system curve of the ducts in the house (which plots the static pressure across the supply and return air ducts as a function of airflow) with the fan curve of the furnace (which plots the static pressure across the furnace as a function of airflow). The intersection of these two curves is the static pressure and the airflow at which the furnace will operate in that house (refer to Figure 6.1).

Furnace fan curves, reported as tables of static pressure rise versus airflow through the furnace, are available from manufacturers in the product literature for each furnace. One of the manufacturers also supplies blower-motor input power as a function of airflow through the furnace.

Air power is calculated from the air speed through the furnace and the pressure rise across the furnace. The overall air-moving efficiency is air power divided by the electric power to the blower. All the electric power to blower motors eventually is converted to heat that contributes to meeting the building heating load.

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[a] A very small share of existing furnaces use belt-drive blowers with shaded-pole motors. That arrangement was less efficient than direct-driven PSC motors, but the airflow from these old model furnaces was less, so electricity consumption was not significantly reduced when this technology became obsolete.

6.1 System Curves

The system curve of the air-distribution system is a graphical representation of the static pressure drop generated across the supply and return ducts in a house for different airflows. The airflow and pressure drop at which the furnace will operate can be determined by the intersection of the system curve of the house and the fan curve of the furnace circulating air blower[4].

We modeled system curves as quadratic curves, which is standard in HVAC design and fan selection books[6]. The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$P = a \times Q^2$$

where;

P = static pressure (in.w.g.);
α = a constant coefficient; and
Q = airflow (cfm).

We selected the coefficient in the system curve equation for each house. It randomly sampled a coefficient from one of four distributions, depending on the nominal maximum airflow of the virtual model furnace selected for that house. We designed each distribution so that 10% of samples would have static pressures below 0.5 in.w.g., and only 1% of the samples would have static pressures greater than 1 in.w.g at the nominal maximum airflow. This is in line with several field studies.[7] To keep the system curves from clumping at the higher pressures, we used a log-normal distribution of values of the coefficient. See Figure 6.1 for an example of a plot of system curves intersecting a furnace fan curve.

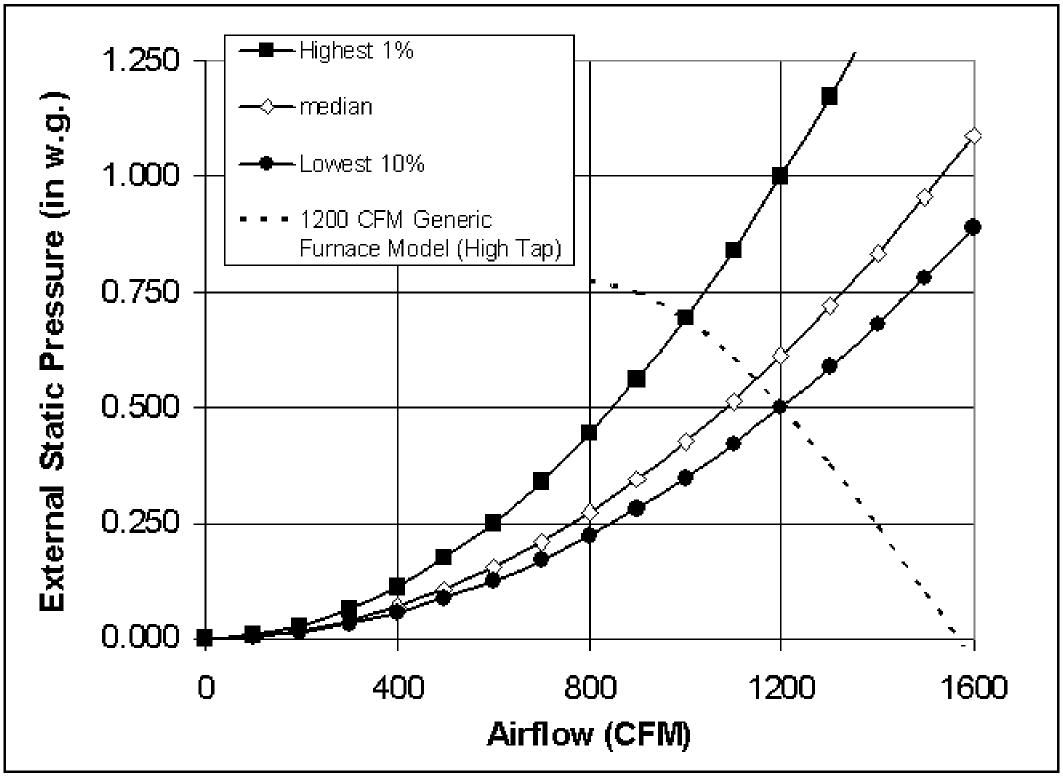

Figure 6.1 Sample of System Curves with a Typical Fan Curve

6.2 Furnace Fan Curves

Depending on the resistance (measured as static pressure at a give flow) of the supply and return air ducts, a furnace will move more or less air through the ducts. When these values are plotted graphically, they are referred to as fan curves.

We assigned three fan curves to each virtual furnace model: one for cooling operation, one for heating, and a third for the low-fire heating operation of modulating design options. The cooling fan curve passes through the nominal maximum-rated airflow point at 0.5 in.w.g. external static pressure. During normal heating operation, airflow is 80% of the nominal maximum airflow at 0.5 in.w.g. external static pressure. The airflow for low-fire heating operation at 0.5 in.w.g. static pressure is 2/3 of the nominal maximum airflow at the same external static pressure.

We developed fan curves for the virtual furnace models. As detailed in Appendix D, Furnace Fan Curves, Figures 6.2–6.5 show the fan curves for the virtual furnace models. From the left, the line closest to vertical axis shows a fan curve for the virtual furnace model operating in low-fire mode, the middle line is for the virtual furnace model operating in heating mode, and the line furthest to the right, which passes through 0.5 in. w.g. static pressure at the nominal maximum of airflow, is the fan curve for the virtual furnace models operating in cooling mode.

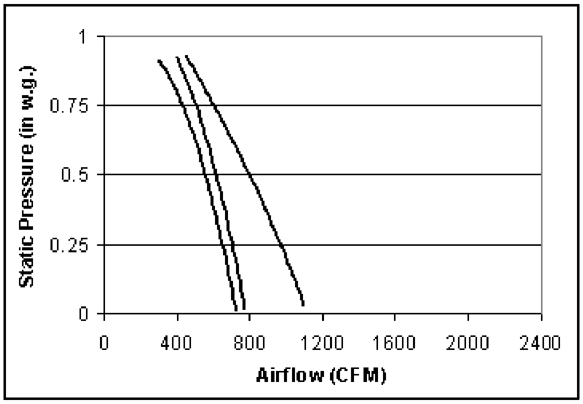

Figure 6.2 Fan Curves for 800 cfm Virtual Furnace Model

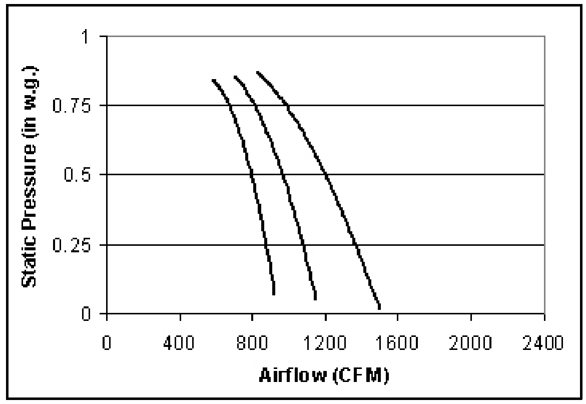

Figure 6.3 Fan Curves for 1200 cfm Virtual Furnace Model

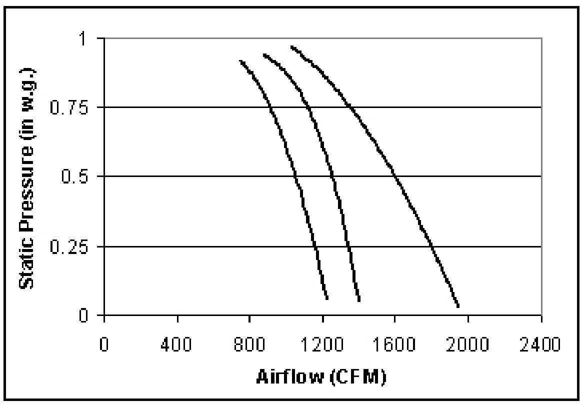

Figure 6.4 Fan Curves for 1600 cfm Virtual Furnace Model

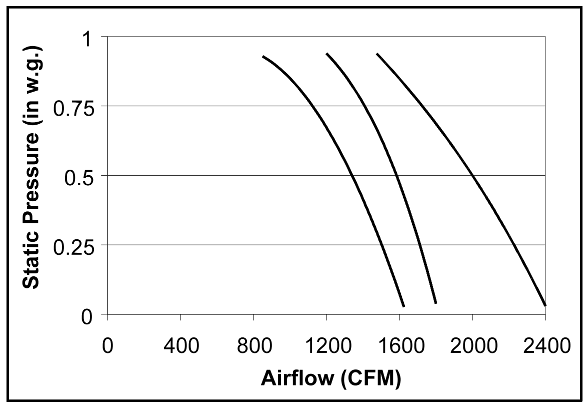

Figure 6.5 Fan Curves for 2000 cfm Virtual Furnace Model

6.3 Overall Air-Moving Efficiency

The overall air-moving efficiency is the air power divided by the electric power used by the blower motor.

Air power, the power added to the air because of its motion and pressure increase as it is forced through the furnace, is calculated as:

$$AP = \left(\frac{745.7}{6356}\right) \times Q \times \left[P + \left(\frac{Q}{4005 \times A}\right)^2 \right]$$

where;

AP	=	air power (watts);
Q	=	airflow (cfm);
$\frac{745.7}{6356}$	=	a conversion factor to put air horsepower in watts;
4005	=	a conversion factor to put the velocity pressure of standard air in i.w.g.;
P	=	external static pressure (in.w.g.); and
A	=	cross-sectional airflow area defined as a supply-air outlet area (sq.ft.).

In addition to airflow at a range of external static pressures one manufacturer reports fan motor electricity consumption as well.[8, 9, 10, 11, 12, 13] This allowed us to calculate the overall efficiency from data in that manufacturers' product literature.

$$\eta overall = \frac{AP}{BE}$$

where;

$\eta_{overall}$	=	overall air moving efficiency;
BE	=	fan motor electricity consumption (W); and
AP	=	air power (W).

We calculated air power and overall efficiency for each point in the fan operating tables for each of the models. To generalize this relation of overall air-moving efficiency to airflow, we transformed airflows to percentages of airflow at free flow for all the furnaces. We did this calculation separately for condensing and non-condensing furnaces. The transformation of airflow to fraction-of-airflow-at-free-flow allowed us to plot all of the curves of overall air-moving efficiency together (see Figure 6.6).

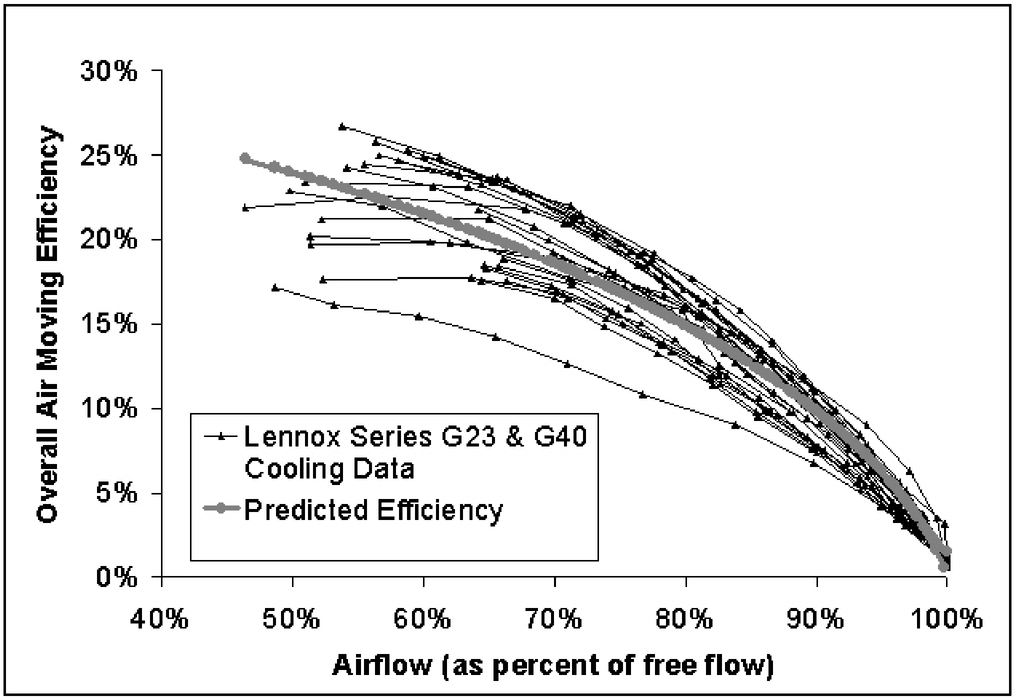

Figure 6.6 Overall Air-Moving Efficiency of Existing Furnaces

We fit these curves to a single equation of overall efficiency as a function of the ratio of airflow to free airflow as follows:

$$\eta_{overall} = c_0 + c_1 \times (1 - Q_0) + c_2 \times (1 - Q_0)^{(1/2)} + c_3 \times (1 - Q_0)^{(1/3)}$$

where;

$\eta_{overall}$	=	overall air moving efficiency;
Q_0	=	ratio of airflow to free flow; and
c_0, c_1, c_2, c_3	=	empirically determined coefficients.

Figures 6.7 and 6.8 show the overall air-moving efficiency for non-condensing and condensing virtual furnace models. For details of the overall air-moving efficiency and tables of coefficients for each of the virtual furnaces and operating modes, see Appendix F, Overall Air Moving Efficiency.

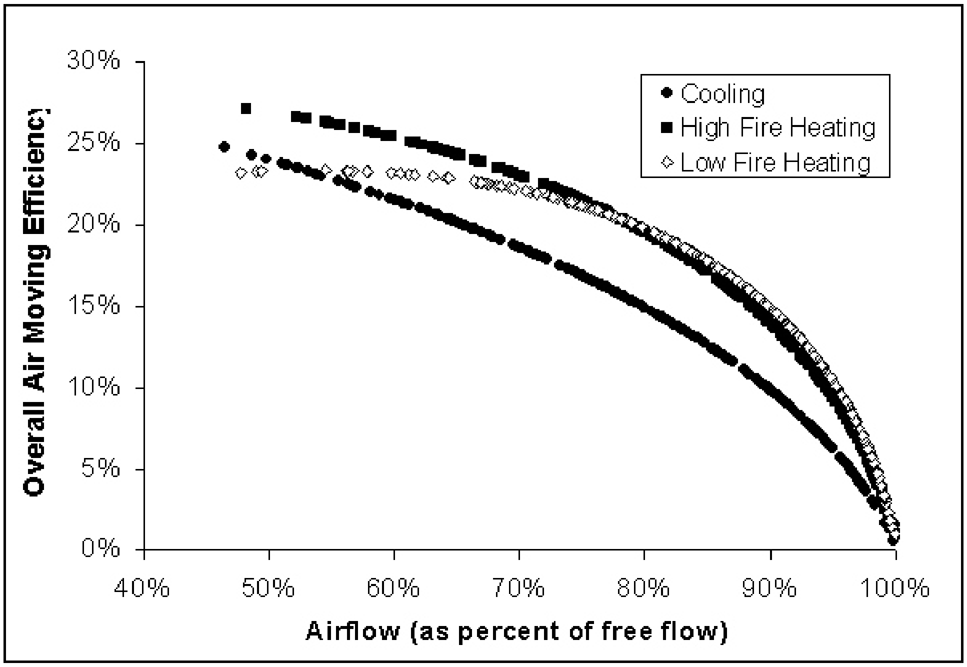

Figure 6.7 Overall Air-Moving Efficiency of Non-Condensing Virtual Furnace Models

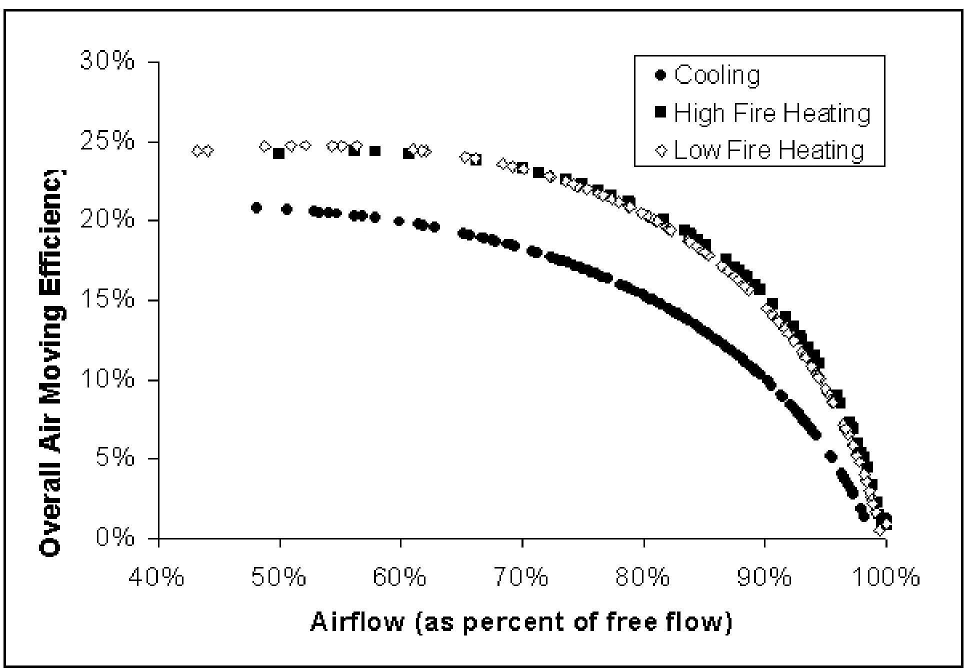

Figure 6.8 Overall Air-Moving Efficiency of Condensing Virtual Furnace Models

6.4 Blower Motor Electricity Consumption

The circulating-air blower motor electricity consumption in steady-state at full-load steady-state is a function of airflow (*Q*), external static pressure (*P*), and the overall air-moving efficiency of the furnace ($\eta_{overall}$).

For a baseline furnace, we calculated the circulating-air fan motor electricity consumption for the forward-curved impeller with a direct-drive PSC motor as the air power divided by the overall air-moving efficiency of the blower and blower motor:

$$BE = \frac{AP}{\eta overall}$$

where;

BE	=	blower motor electricity consumption (W);
AP	=	air power (W); and
$\eta_{overall}$	=	overall air moving efficiency.

7 ANNUAL HEATING AND COOLING LOADS IN SAMPLE HOUSES

7.1 Annual House Heating Load

The annual house heating load (HHL) is the total amount of heat output from the furnace that the house needs for an entire year. This includes heat from the burner and heat from the blower and the blower motor.

Burning operating hours (BOH), the number of hours the furnace burner is on during a year, is a key variable in the calculation of HHL. We calculated BOH for the existing furnace as:

$$\text{BOH} = \frac{Q_{yr}}{Q_{in}}$$

where;

BOH	=	burner operating hours (hrs/yr);
Q_{yr}	=	annual fuel consumption for heating the house~~-~~, from RECS97 (kBtu/yr); and
Q_{in}	=	input capacity of the existing furnace (kBtu/hr).

We determined HHL for each sampled household, based on the BOH and the characteristics of the assigned existing furnace, using the following calculation:

$$HHL = \left[Qin \times AFUEex + 3.412 \times y \times BE\right] \times BOH$$

where;

Q_{in}	=	input capacity of existing furnace (kBTU/hr);
$AFUE_{ex}$	=	AFUE of existing furnace;
3.412	=	constant to convert kW to kBTU/hr;
y	=	ratio of blower on-time to burner on-time (from DOE test procedure); and
BE	=	power consumption of the blower motor (kW).

The power consumption of the blower motor depends on the steady-state operating conditions (the pressure and airflow) for the furnace. This calculation is explained in Section 6, Calculating Furnace Blower Electricity Consumption.

7.2 Annual House Cooling Load

The annual house-cooling load (HCL) is the total amount of cooling provided to the house for the entire cooling season. It includes the cooling provided by the existing air conditioner, and accounts for the waste heat from the inefficiencies of the blower and blower motor. We calculated HCL from the cooling energy consumption reported in RECS97 and the SEER of the assigned existing air conditioners:

$$HCL = Q_{cool} \times SEER_{ex}$$

where:

HCL	=	annual house-cooling load (kBtu/h/yr);
Q_{cool}	=	annual house-cooling electricity consumption, from RECS97 kWh/yr); and
$SEER_{ex}$	=	SEER of the existing air conditioner (kBtu/h/kW).

8 FURNACE ENERGY CONSUMPTION IN SAMPLE HOUSES

Once the heating and cooling loads of each sample house are known, it is possible to estimate what the energy consumption of alternative (more efficient) furnaces would be if the more-efficient furnaces, rather than the existing equipment, were used in each house.

We calculated the energy consumption for furnaces and boilers incorporating a variety of design options that increase efficiency. The design options shown in Table 8.1 were those that met the screening criteria used by DOE in its standards rulemaking. Some options were considered for one or more product classes but not for others (e.g., condensing operation). Lekov et al. provide a discussion of the design options.[14]

Table 8.1 Design Options Considered by Product Class

Design Option	Gas Furnaces: Non-weatherized	Gas Furnaces: Weatherized	Oil-fired Furnace	Manuf-Home Gas furn	Hot Water Boilers: Gas	Hot Water Boilers: Oil
					Gas	Oil
Improved Heat Exchanger	Y	Y	Y	Y	Y	Y
Modulating Operation*	Y	Y	Y	Y	Y	Y
Improved or Increased Insulation	n/a	Y	n/a	n/a	n/a	n/a
Condensing Secondary Heat Exchanger	Y	N	N	Y	Y	Y
Electronic Ignition	b	b	b	Y	Y	b
Induced or Forced Draft	b	b	b	Y	Y	b
Air-Atomized Burner with Modulation	n/a	n/a	Y	n/a	n/a	Y
Increased Motor Efficiency	Y	Y	Y	Y	Y	Y
Increased Blower Impeller Efficiency	Y	Y	Y	Y	n/a	n/a

Y = The design option was considered for this product class.
N = The design option was not considered for this product class.
b = The design option is already in the baseline model of this product class.
n/a = The design option is not applicable to this product class.
* Two-stage or step modulation

8.1 Blower Motor Electricity Design Options

The electricity consumption of the circulating air blower motor (BE) affects both fuel and electricity consumption. Improving the efficiency of the circulating-air blower in a gas furnace will reduce electricity consumption, and therefore, slightly reduce the amount of heat contributed to the airflow. To make up for the decrease of heat from the motor, there will be a slight increase of gas consumption. Section 6.4, Blower Motor Electricity Consumption, described the calculation of BE for virtual models.

The baseline design for the circulating-air blower is a centrifugal blower with forward-curved blades powered by a PSC induction motor. The LCC analysis considered three design options to improve blower efficiency: 1) an improved PSC motor (PSC+); 2) an electronically-commutated motor (ECM); and 3) a backward-curved blower impeller with a different ECM motor (BC/ECM+).

The PSC+ is a motor with a dedicated lamination design using higher-grade electrical steel and tighter windings, with proportionately more copper to limit winding losses. ECM motors have permanent magnets on the rotor. By changing the frequency and voltage on the stator coils, the speed and torque of the motor can be adjusted. The BC/ECM+ motor operates at a higher speed, has a smaller diameter, and has improved magnets and electronics. Furnaces with ECM and BC/ECM+ blower motors are programmed to take advantage of the adjustable speed and torque of ECM motors to provide constant airflow, regardless of the static pressure. This is the equivalent of a vertical fan curve at the nominal airflow of the furnace.

Calculation of BE varies with each electricity design option.

For the PSC+ design option,

$$BE = \frac{AP}{\eta overall \times scalar}$$

where:

AP	=	air power (W),
$\eta_{overall}$	=	overall efficiency, and
$scalar$	=	the incremental motor efficiency gain from the PSC+ design option.

AP and $\eta_{overall}$ depend on static pressure and airflow, as described in section 6.3 on Overall Air-Moving Efficiency.

For the ECM design option, we developed a series of equations to calculate the blower speed and shaft power from the furnace static pressure and airflow, the blower-motor efficiency from the shaft power and speed, and the blower-motor power consumption from the efficiency and shaft power. We developed these equations for ECM motors from product literature of a motor manufacturer.[15] See Appendix G, Power Consumption of ECM Blower Motors.

For the BC/ECM+ design option, we developed an equation for BE as a function of static pressure and airflow from a prototype backward-inclined blower developed by General Electric.[16] The static pressure and airflow is determined from the intersection of the duct system curve and the vertical fan curve of a furnace, as with an ECM motor. This is explained further in Appendix H, Power Consumption of BC/ECM+ Blower Motors.

8.2 Fuel Consumption

For each design option, the BOH is different, since the AFUE, and blower-motor electricity consumption are different. Therefore, each design option and efficiency level requires a different operating time to heat the same house. We calculated BOH as:

$$BOH = \frac{HHL}{Qin \times AFUE + 3.412 \times y \times BE}$$

where:

Q_{in}	=	input capacity of existing furnace (kBTU/h);
$AFUE$	=	AFUE of design option or efficiency level being considered;
3.412	=	a constant to convert kW to kBTU/h;
y	=	the ratio of blower on-time to burner on-time; and
BE	=	the power consumption of the blower motor (kW).

BE varies with airflow and static pressure, which are determined by the intersection of the furnace fan curve and the duct system curve.

We calculated the furnace fuel consumption for each design option and efficiency level using the following formula:

$$Fuel\_Use = BOHxQin$$

where:

BOH	=	burner operating hours (h);
Q_{in}	=	input capacity of existing furnace (kBTU/h).

8.3 Electricity Consumption

We calculated furnace electricity consumption for the blower, the draft inducer, and the igniter.[a] The blower moves heated air through the house whenever the furnace is on. It also operates in the cooling season (summer) if the house is air-conditioned. Since the efficiency of the blower will have different impacts on the overall energy consumption of the furnace in different seasons, the electricity use calculation must be carried out separately for winter and summer. We calculated the winter electricity consumption as:

[a] The DOE and ASHRAE test procedures do not count the electricity used by controls when the furnace is not firing.

$$ElecWinUse = BOH \times \left(y \times BE + y_p \times PE + y_{ig} \times PE_{ig}\right)$$

where:

BOH	=	burner operating hours (h);
y	=	ratio of blower on-time to burner on-time;
BE	=	power consumption of the blower motor (kW);
y_P	=	ratio of induced-draft blower on-time to burner on-time;
PE	=	power consumption of the draft-inducer blower-motor (kW);
y_{IG}	=	ratio of ignitor on-time to burner on-time; and
PE_{IG}	=	power consumption of the ignitor (kW).

The ratio of blower on-time to burner on-time and the ratio of induced draft blower on-time to burner on-time are from the ASHRAE test procedure[17] using delay times for the virtual model furnaces. The ratio of ignitor on-time to burner on-time comes from the DOE test procedure[18] and the ignition time of the virtual model furnaces.[a]

The details for calculating energy consumption of modulating furnaces appear in Appendix I, Electricity and Gas Use for Modulating Furnaces.

The summer furnace electricity consumption is only the electricity use by the circulating-air blower fan that moves the air cooled by the air conditioner. During cooling mode, the blower motor will operate at a higher speed, so the airflow and static pressure conditions will be different from the heating mode. We calculated summer electricity use as:

$$ElecSumUse = ACOHexisting \times BEcool$$

where:

$ACOHexisting$	=	air-conditioner operating hours (h/yr); and
BE_{cool}	=	power consumption of the blower-motor in cooling mode (kW).

A more efficient blower and blower-motor will reduce the air conditioning hours, since not as much heat from the blower and blower motor will be added to the cooled airstream. However, the annual household cooling load does not change. The cooling provided by the air-conditioning system must remain the same, so the air-conditioner operating hours are reduced. See Appendix J, Air Conditioner Operating Hours, for the derivation of these calculations. We

[a] The ASHRAE test procedure does not deal with ignitor energy consumption.

calculated the new air-conditioner operating hours as:

$$AC\_OH_{new} = \frac{AC\_OH_{existing}}{1+\left(\frac{\dot{Q}_{heating\_existing} - \dot{Q}_{heating\_new}}{AC_{capacity}}\right)}$$

where:

$\dot{Q}_{heating}$	=	rate at which the blower and blower motor add heat to the air stream (Btu/h); and
$AC_{capacity}$	=	cooling capacity of the air conditioner (Btu/h).

9 BOILER ENERGY CONSUMPTION

To assign the input capacity for the energy consumption calculation for hot-water boilers, we used the input capacities of the virtual model furnaces for boilers, weighted according to the shipment data from GAMA.[3] We calculated the heating load for the house and the energy consumption of different model designs in a similar manner as for furnaces. The power consumption of the circulating pump motor is fixed at 62 watts for the baseline model design.[19] The improved circulating pump uses 42 watts.

We calculated the winter fuel consumption for each design option for boilers using the same approach as for furnaces.

10 ENERGY CONSUMPTION RESULTS

The tables in this section present average annual gas or oil consumption, winter electricity consumption, and summer electricity consumption (where relevant) for selected design options in each product class. Lekov et al. provide a discussion of the design options.[14]

As explained in Lutz et al.,[2] the average consumption in each product class considers those sample households that use that type of heating equipment. Thus, the values reflect house characteristics and climate zone as well as equipment efficiency.

Table 10.1 shows the average consumption in each product class for the most common type of equipment. The average fuel use is higher for oil-fired than for gas-fired equipment because the former are used in houses in colder climates. The high winter electricity use of oil-fired furnaces reflects the greater fan utilization over a long heating season. The relatively low fuel use of weatherized gas furnaces and manufactured home furnaces reflects their location in warm climates, whereas the high summer electricity use of weatherized gas furnaces reflects greater fan utilization during the cooling season.

Table 10.1 Annual Energy Consumption of Typical Heating Equipment in Each Product Class

Product Class (AFUE)	Average Annual Gas or Oil Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
Non-weatherized gas furnaces (80%)	64.8	476	157
Weatherized gas furnaces (80%)	39.3	291	372
Manufactured-home furnaces (80%)	45.0	405	229
Oil-fired furnaces (81%)	84.7	759	71
Hot water gas boilers (82%)	87.7	375	n.a.
Hot water oil-fired boilers (84%)	103.6	363	n.a.

Table 10.2 Annual Energy Consumption of Non-Weatherized Gas Furnaces by Design Option

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	66.4	488	157
80%	64.8	476	157
80% PSC+	64.8	459	149
80% ECM	65.5	399	118
80% BC/ECM+	66.8	240	77
80% 2-stage Modulation.	63.4	475	157
80% 2-stage Modulation. ECM	64.8	246	118
80% 2-stage Modulation. BC/ECM+	65.3	201	77
81%	64.1	470	154
81% PSC+	64.1	454	149
81% ECM	64.7	296	118
81% BC/ECM+	65.0	237	77
81% 2-stage Modulation	62.7	470	157
81% 2-stage Modulation ECM	64.0	243	118
81% 2-stage Modulation BC/ECM+	64.5	198	77
82%	63.2	465	157
82% PSC+	63.3	448	149
82% ECM	63.9	293	118
82% BC/ECM+	64.2	234	77
82% 2-stage Modulation	62.0	464	157
82% 2-stage Modulation ECM	63.3	240	118
82% 2-stage Modulation BC/ECM+	63.7	196	77
83%	62.5	459	157
90% Condensing	57.8	421	157
90% PSC+	57.9	407	149
90% ECM	58.3	278	118
90% BC/ECM+	58.5	224	77
91% 2-stage Modulation ECM	57.2	239	118
91% 2-stage Modulation BC/ECM+	57.5	197	77

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
91% Step Modulation ECM	56.8	237	118
91% Step Modulation BC/ECM+	57.3	196	77
92% Increased HX Area	56.6	412	157
92% PSC+	56.6	398	149
92% ECM	57.1	272	118
92% BC/ECM+	57.3	219	77
93% 2-stage Modulation ECM	56.0	234	118
93% 2-stage Modulation BC/ECM+	56.3	193	77
93% Step Modulation ECM	55.6	232	118
93% Step Modulation BC/ECM+	56.1	192	77
96% Step Modulation ECM	53.9	225	118
96% Step Modulation BC/ECM+	54.3	186	77

Table 10.3 Annual Energy Consumption of Weatherized Furnaces by Design Option

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	40.3	298	372
80% Increased HX Area	39.3	291	372
80% Improved Insulation	39.1	290	372
80% PSC+	39.3	281	354
80% ECM	39.7	182	281
80% Improved Heat Transfer	39.3	291	372
81% Increased HX Area	38.8	288	372
81% Improved Insulation	38.7	286	372
81% PSC+	38.9	277	354
81% ECM	39.3	180	281
81% Improved Heat Transfer	38.8	288	372
82% Increased HX Area	38.3	284	372
82% Improved Insulation	38.2	283	372
82% PSC+	38.4	274	354
82% ECM	38.8	178	281
82% Improved Heat Transfer	38.3	284	372
83% Increased HX Area	37.9	281	372
83% Improved Insulation	37.8	280	372
83% PSC+	37.9	271	354
83% ECM	38.3	176	281
83% Improved Heat Transfer	37.9	281	372

Table 10.4 Annual Energy Consumption of Manufactured-Home Gas Furnaces by Design Option

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
75% Baseline	50.8	374	229
80%	45.0	405	229
80% ECM	45.8	221	126
80% 2-stage Modulation	43.9	398	229
81%	44.5	400	229
81% ECM	45.3	218	126
81% 2-stage Modulation	43.4	393	229
82%	44.0	395	229
82% ECM	44.7	216	126
82% 2-stage Modulation	42.9	389	229
90%	40.2	359	233

Table 10.5 Annual Energy Consumption of Oil Furnaces by Design Option

Design Option (AFUE and technology description)	Average Annual Oil Use (MMBtu)	Average Winter Electricity Use (kWh)	Average Summer Electricity Use (kWh)
78% Baseline	87.8	787	71
80%	85.7	768	71
81% Increased HX Area	84.7	759	71
81% Atomized Burner 2-stage Modulation.	82.6	845	71
81% Interrupted Ignition	84.8	727	71
81% ImprovedSupplyFanMotor (ECM)	85.6	534	57
82%	83.7	750	71
82% Atomized Burner 2-stage Modulation.	81.6	836	71
82% Interrupted Ignition	83.8	719	71
82% ImprovedSupplyFanMotor (ECM)	84.6	527	57
83%	82.7	741	71
83% Atomized Burner 2-stage Modulation.	80.7	826	71
83% Interrupted Ignition	82.8	710	71
83% ImprovedSupplyFanMotor (ECM)	83.6	521	57
84%	81.7	733	71
84% Atomized Burner 2-stage Modulation.	79.8	817	71
84% Interrupted Ignition	81.8	702	71
84% ImprovedSupplyFanMotor (ECM)	82.6	515	57
85%	80.8	724	71
85% Atomized Burner 2-stage Modulation.	78.9	807	71
85% Interrupted Ignition	80.9	694	71
85% ImprovedSupplyFanMotor (ECM)	81.6	509	57

Table 10.6 Annual Energy Consumption of Hot Water Gas Boilers by Design Option

Design Option (AFUE and technology description)	Average Annual Gas Use (MMBtu)	Average Winter Electricity Use (kWh)
80% Baseline	93.5	379
81%	88.8	380
81% 2-stage Modulation + Induced Draft	87.4	562
81% Improved Circulation Pump	89.0	338
82%	87.7	375
82% 2-stage Modulation + Induced Draft	86.4	555
82% Improved Circulation Pump	87.9	334
83% Improved Heat Transfer / Elec. Ignition	86.7	371
83% 2-stage Modulation + Induced Draft	85.4	549
83% Improved Circulation Pump	86.9	330
84%	85.7	367
84% 2-stage Modulation + Induced Draft	84.4	542
84% Improved Circulation Pump	85.8	326
88%	81.8	350
91%	79.3	301
99%	73.0	277

Table 10.7 Annual Energy Consumption of Hot Water Oil Boilers by Design Option

Design Option (AFUE and technology description)	Average Annual Oil Use (MMBtu)	Average Winter Electricity Use (kWh)
80% Baseline	108.7	381
81%	107.4	377
81% Atomized Burner 2-stage Modulation	105.9	567
81% Interrupted Ignition	107.5	345
81% Improved Circulation Pump	107.5	338
82%	106.1	372
82% Atomized Burner 2-stage Modulation	104.6	560
82% Interrupted Ignition	106.2	341
82% Improved Circulation Pump	106.2	334
83%	104.8	368
83% Atomized Burner 2-stage Modulation	103.4	554
83% Interrupted Ignition	104.9	337
83% Improved Circulation Pump	105.0	330
84%	103.6	363
84% Atomized Burner 2-stage Modulation.	102.2	548
84% Interrupted Ignition	103.7	333
84% Improved Circulation Pump	103.7	326
86%	101.2	355
86% Atomized Burner 2-stage Modulation.	99.9	535
86% Interrupted Ignition	101.3	325
86% Improved Circulation Pump	101.3	319
90%	97.0	276
95%	91.9	262

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